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Fluoride and Dental Caries Prevention in Children

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Dr Lewis has disclosed no financial relationships relevant to this article. This commentary does contain a discussion of an unapproved/investigative use of a commercial product/device.

Practice Gaps

1. Low-income children experience more dental caries and more complications of caries, such as dental abscesses. Beginning fluoride toothpaste and fluoride varnish during the first year of life can reduce low-income children's risk of getting dental caries.
2. Pediatricians and other primary care clinicians for children have an important role to play in implementing a dental caries primary prevention program for all children, which should include regular use of fluoride as the mainstay.
3. Fluoride toothpaste and community water fluoridation benefit both children and adults, decreasing the risk of dental caries throughout the life span.

Objectives After completing this article, readers should be able to:

1. Understand the mechanism that leads to dental caries.
2. Understand how fluoride prevents dental decay.
3. Be knowledgeable of the various sources of fluoride.
4. Be aware of evidence to support safe use of fluoride and how to counter misinformation perpetuated by antifluoride groups.
5. Be able to recommend specific fluoride modalities, depending on the child's risk for dental caries.

Introduction

Fluoride is a valuable caries prevention modality that has a large body of evidence supporting its use. Because infants, young children, and their parents typically visit the pediatric office many times before ever seeing a dentist, parents may bring questions about fluoride to their pediatricians. Moreover, health supervision visits provide unique opportunities for pediatricians to address fluoride in the context of preventive oral health. However, until recently, pediatricians typically received little training in oral health and therefore may need additional education about fluoride to answer parents' questions, counter misinformation, and ensure appropriate use of fluoride among their patients. Given that approximately one-quarter of US children younger than 5 years have caries, it is particularly important that pediatricians are knowledgeable about fluoride and comfortable with delivering it to their patients.

Fluoride is highly effective in preventing dental caries (commonly known as dental decay), with both primary and secondary preventive properties. By definition, primary prevention precedes the onset of disease so that disease is avoided. An example of primary prevention is regular consumption of fluoridated water, which provides adequate topical exposure to fluoride to prevent dental caries. Secondary prevention involves early identification of caries so it can be arrested or reversed. An example is fluoride varnish (FV) application to white spot lesions, which are the white, chalky spots at the gingival margins that are the first visible evidence of caries. FV remineralizes these areas and reverses the decay process.

Abbreviations

CWF:	community water fluoridation
ECC:	early childhood caries
FDA:	Food and Drug Administration
FPL:	federal poverty level
FTP:	fluoride toothpaste
FS:	fluoride supplement
FV:	fluoride varnish
NHANES:	National Health and Nutrition Examination Survey

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Effect of Dental Caries in Childhood

Caries begins in childhood and eventually affects 90% of adults. Even so, dental decay's effect on low-income individuals is disproportionate, leading to earlier onset, more affected teeth, complications, and ultimately teeth lost during adulthood because of caries. Results of the National Health and Nutrition Examination Survey (NHANES) III during 1999–2004, indicated that 24% of 2- to 4-year-olds and 51% of 6- to 8-year-olds had caries in primary teeth. (1) Among 12- to 19-year-olds, 59% had caries in permanent teeth. Children living below 200% of the federal poverty level (FPL) had more caries relative to children at or above 200% of the FPL (Figure 1). (1) Caries prevalence has decreased over time in all age categories, but this trend recently reversed for 2- to 4-year-olds, with a 5% increase (from 19% to 24%) since 1988–1994 (NHANES II). (1) The reasons for this increase are unclear.

The proportion of US children with *untreated* caries has remained approximately the same since 1988–1994. In 1999–2004, 16% of 2- to 4-year-olds and 28% of 6- to 8-year-olds had untreated caries in primary teeth, whereas 20% of 12- to 19-year-olds had untreated caries in permanent teeth. (3) Children living below 100% of the FPL had 2 to 3 times as many untreated caries as children living above 200% of the FPL. (3) Insurance and income-based disparities in access to dental care are important contributors to these differences in untreated caries. (4)(5) Despite mandated dental care coverage for low-income children under the Early and Periodic Screening, Diagnosis, and Treatment (EPSDT) program (6) and,

more recently, the State Children's Health Insurance Program (7) and the Children's Health Insurance Program Reauthorization Act, (8) it remains difficult for publicly insured children to access professional dental care, in part because fewer dentists accept Medicaid. (9) In 2008, just 38% of Medicaid-enrolled children, ages 2 to 18 years, received dental care in the previous year. (9)

Untreated caries can lead to toothache and other more serious medical problems. In 2008, approximately 15,000 US children presented to emergency departments with toothache cited as the reason for their visit. (10) Some of these children required hospital admission and/or surgery. In a well-publicized case in 2007, a Maryland boy died of complications resulting from dental caries. (11) Analysis of the 2007 National Survey of Children's Health documented that 14% of elementary school children had experienced toothaches in the previous 6 months. (12) Being from a low-income family, of minority race, or having special health care needs independently increased risk of toothache. (12)

Dental Decay Pathophysiology

Dental decay is a transmissible infectious disease in which cariogenic bacteria are passed from mother (usually) to child. *Streptococcus mutans* and *Lactobacillus* species, among other bacteria, produce acids as end products of carbohydrate metabolism. These acids dissolve the calcium-phosphate mineral of a tooth's enamel during a process called demineralization. If not reversed through remineralization, the tooth structure erodes until the demineralized area collapses, resulting in a cavity. (13)

A balance of caries-promoting and caries-inhibiting factors is constantly in play (Figure 2).

Caries may affect primary or permanent dentition. Caries in the primary teeth of children younger than 6 years is referred to as early childhood caries (ECC). A typical pattern of decay in ECC is that caries first develops on the smooth surfaces of the maxillary primary incisors; ECC may then progress quickly to the remaining primary dentition. This pattern differs from that in the permanent teeth of older children and adults, in whom the occlusal surfaces of molars are most often affected. Older adults may experience caries in crown or root

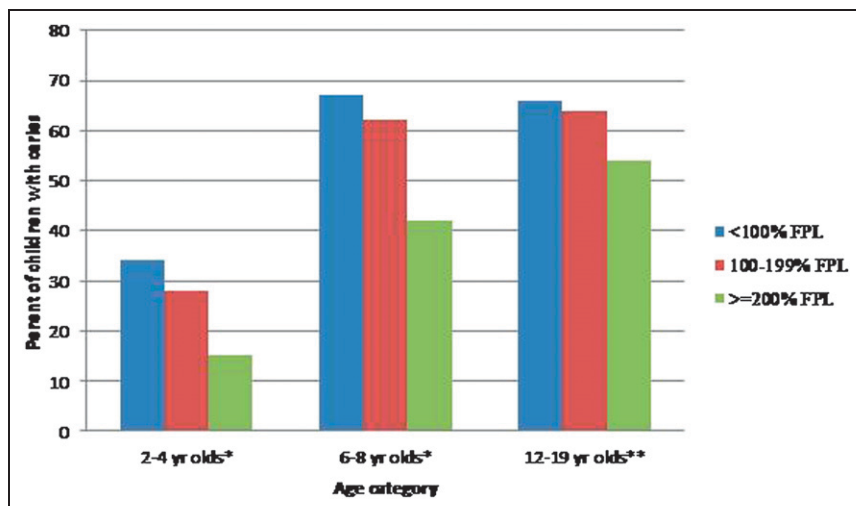


Figure 1. Percentage of US children with dental caries by federal poverty level (FPL) category (National Health and Nutrition Examination Survey III, 1999–2004). (1)(2)

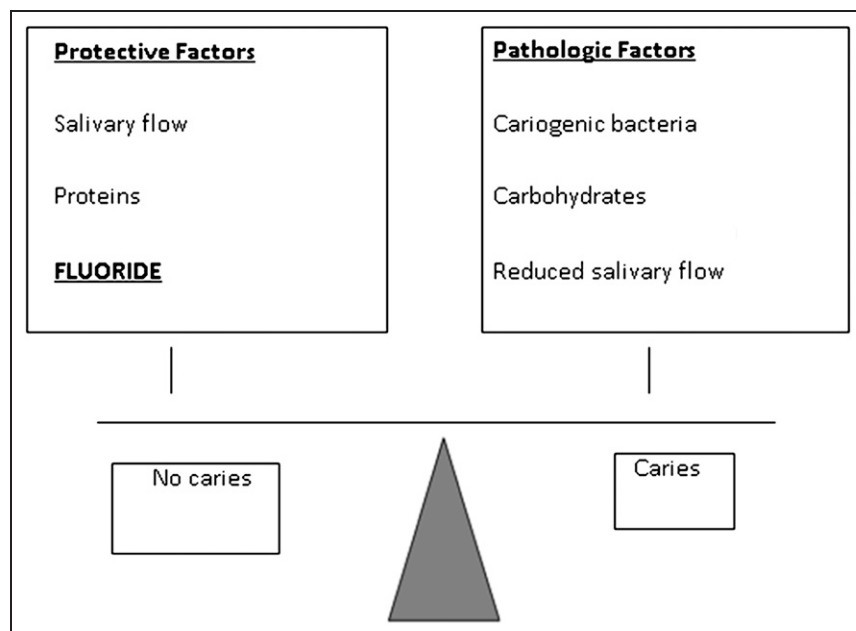


Figure 2. Ongoing balance between caries protective and pathologic factors. Fluoride can help to tip the balance in the direction of remineralization or "no caries" provided that pathologic factors are not overwhelming.

surfaces, which become vulnerable to decay as gum tissue recedes.

Caries Risk Factors

Caries disproportionately affects certain individuals and groups, predominantly defined by poverty. (1) Exactly how poverty interacts with other variables to produce higher levels of caries is incompletely understood. However, caries risk factors would be expected to cluster within families and communities because resources, habits, cultural and other beliefs, parental role modeling, and dietary and oral hygiene habits are more likely to be shared by family and community members.

Child-level characteristics associated with more caries include previous caries, (14) visible plaque, (15) consumption of sweetened liquids and candy, (15)(16) (17) suboptimal fluoride exposure, (18) and infrequent toothbrushing. (19)

Caregivers who harbor more cariogenic bacteria, because of untreated caries and/or poor oral hygiene, transmit more bacteria and infect children at younger ages. (16)(20)(21)(22) On the basis of some research evidence, interrupting vertical transmission of cariogenic bacteria is a potential strategy to prevent caries in young children. (23)(24) Other parental factors associated with more caries in their children include multiple decayed

teeth, (25) maternal tooth loss from caries, (26) fewer years of maternal education, (23)(27) less than twice-daily toothbrushing, (28) and fatalistic oral health beliefs. (17)

Despite many variables associated with increased caries risk, predicting precisely which children are at higher risk for caries *before* onset of dental decay is a still-evolving science. Because children at high risk for caries develop ECC within the first few years of life, caries risk assessment should ideally take place *before* first tooth eruption and then be followed by implementation of an appropriate caries prevention program. However, the American Academy of Pediatric Dentistry's Caries-risk Assessment Tool (29) and other caries risk screening tools rely on a history or presence of caries or predisposing dietary and/or oral health habits. Yet, if caries or habits associated with caries are *already* present, then it is *too late* for optimal primary prevention. Low-income status (below 200% of the FPL) is the only caries risk factor that can reasonably be ascertained at first tooth eruption and thus is an appropriate criterion for initial assignment to an intensive caries prevention approach.

Fluoride's Mechanism For Caries Prevention and Fluorosis

Fluoride is a ubiquitous mineral. It is found in all soil, bodies of water, plants, and animals and, as such, is a normal constituent of all diets. (30) Early fluoride researchers believed that fluoride achieved its decay-inhibitory effects in a preeruptive fashion, that is, through incorporation into teeth before eruption via a systemic mechanism. Under this assumption, fluoride benefited only young children. On the basis of in vitro, clinical, and epidemiologic evidence, fluoride's effects are now known to be primarily posteruptive via a topical mechanism. (31)(32) When low levels of fluoride are sustained in saliva (after drinking fluoridated water or brushing with fluoride toothpaste [FTP]), the enamel demineralization and remineralization balance is pushed toward remineralization. Fluoride aids in incorporation of calcium and phosphate into enamel and is itself incorporated into enamel during mineralization. (33)

Fluoride-containing enamel, fluoroapatite, is harder and less acid soluble than the original enamel it replaces. Implications of fluoride's posteruptive mechanism are 2-fold: (1) topical fluoride is more effective than supplements that are swallowed, and (2) fluoride has beneficial effects throughout the lifespan.

Excess fluoride intake can result in fluorosis. Dental fluorosis refers to localized changes to tooth enamel, presenting in its mild forms as white markings on the teeth (Figure 3A and B) with more distinct white marking seen in moderate fluorosis (Figure 3C). (34) It is caused by elevated fluoride ingestion during tooth development. (35) Aesthetic considerations for fluorosis are most important in permanent maxillary incisors (the most visible teeth), which are most susceptible to fluorosis before age 2 years. (36)(37)(38)(39) Once permanent teeth mineralization is complete, by 8 years old, there is no longer risk of additional dental fluorosis with further fluoride exposure. (40) It is recommended that fluoride intake in children not exceed 0.05 to 0.07 mg/kg daily. (41) Above this range, an unacceptable degree of fluorosis may result. Below 0.05 mg/kg, fewer children develop fluorosis, but more children develop caries. (42) Early fluoride studies, before community water fluoridation (CWF) or availability of fluoride-containing dental products, established that there is not a single definable level

of fluoride intake that maximizes caries prevention without at least some dental fluorosis on a population level. (43) The goal is to limit the degree of fluorosis and number of individuals affected without tipping the balance toward higher caries prevalence. Almost all fluorosis in the United States is very mild or mild (Figure 4); (44) teeth with this degree of fluorosis are more resistant to caries than teeth without fluorosis. More severe dental fluorosis, which manifests as enamel pitting and predisposition to staining (Figure 3D), is unusual in the United States but occurs in other parts of the world where there are naturally high levels of fluoride in the water (eg, >2 ppm). Teeth with severe fluorosis are paradoxically more susceptible to caries.

As opposed to the localized effects of dental fluorosis, skeletal fluorosis is a systemic condition caused by long-term exposure to excessively high levels of fluoride—either ingested or inhaled. Chronic fluoride toxicity leads to poor quality bone and painful calcification and ossification of tendons and ligaments. (45) Skeletal fluorosis is extremely rare in the United States (41) but is endemic in parts of India, China, and Africa. (46) When described in the United States, it is typically in individuals who drink large quantities of black tea or very concentrated black tea (black tea naturally contains fluoride). For example, in a 2013 case report in the *New England Journal of Medicine*, a 47-year-old woman who presented with skeletal fluorosis “reported that for the past 17 years she has habitually consumed a pitcher of tea made from 100 to 150 tea bags daily.” (47) There has not been a reported case of skeletal fluorosis resulting from drinking optimally fluoridated water.

Sources of Fluoride Community Water Fluoridation

CWF is considered among the 10 greatest US public health achievements of the 20th century (48) and one of the few public health interventions with clear-cut, significant cost-effectiveness. (49) CWF refers to the addition of fluoride to that naturally present in water to attain an optimal fluoride level to prevent caries. According to a Centers for Disease Control and

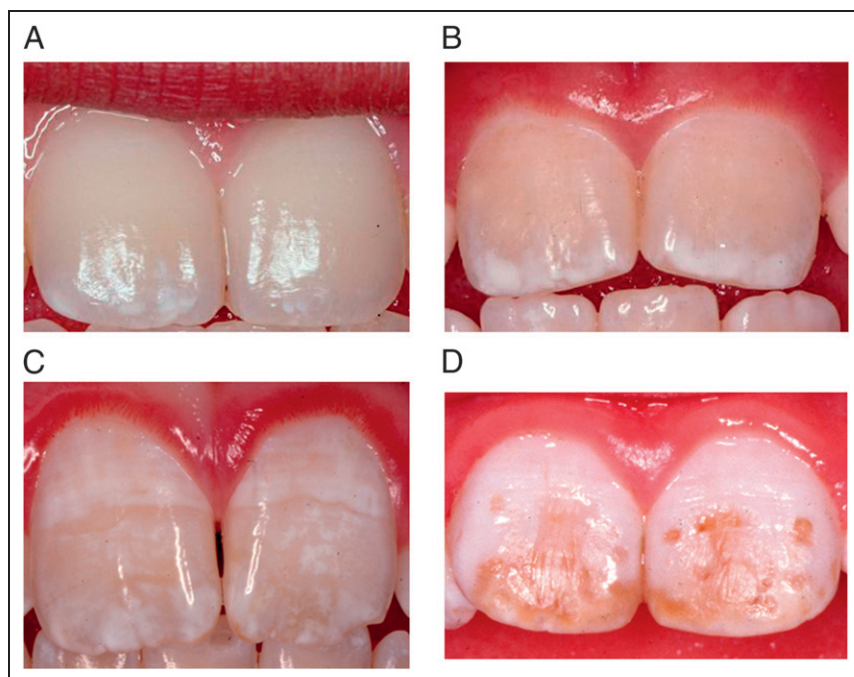


Figure 3. Fluorosis categorized as very mild (A), mild (B), moderate (C), and severe (D). (81)

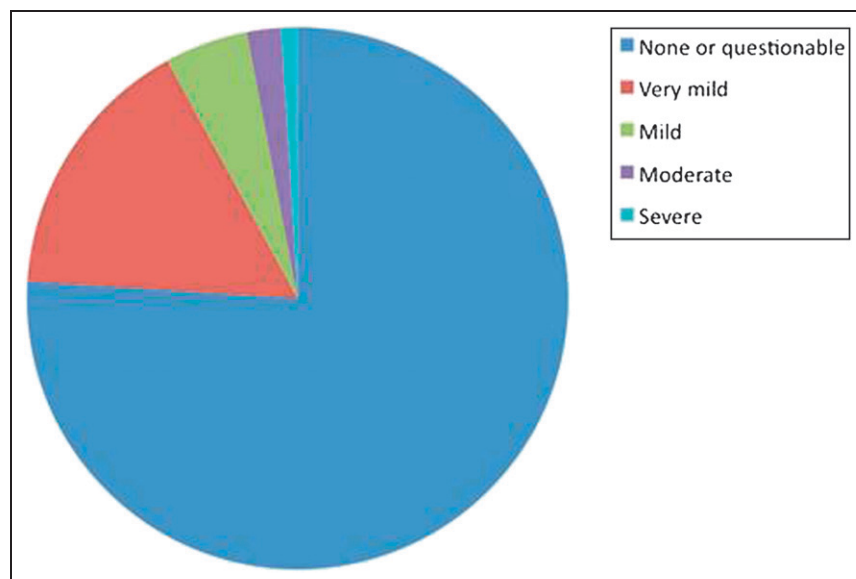


Figure 4. Proportion of 6- to 49-year-olds in the United States with dental fluorosis by severity (National Health and Nutrition Examination Survey III, 1999–2004). (97)

Prevention fluoridation census in 2010, 72% of Americans on public water systems receive CWF. (49) The concept of CWF began with observations in the early 20th century that individuals drinking naturally fluoridated water were more resistant to dental decay. (50) Landmark investigations in the 1940s of 21 cities with varying levels of naturally occurring fluoride in the water identified 1 ppm of fluoride in water as the level maximizing caries prevention while minimizing fluorosis risk. (51) (52) Prospective field trials of CWF in 4 pairs of treatment-control cities in the United States and Canada demonstrated that CWF resulted in a 50% to 75% reduction in caries. (53) In 1945, Grand Rapids, Michigan, was the first US city to fluoridate its public water. (54) CWF also decreases coronal and root caries among adults and has reduced the number of teeth lost to caries in adulthood. (35)(55) A 2007 meta-analysis estimated a caries preventive fraction for CWF in adults to be 27% (the preventive fraction refers to the reduction in carious lesions that can be attributed to drinking fluoridated water; in this case, there were 27% fewer carious lesions relative to adults who did not drink fluoridated water). (56)

Recently, the US Department of Health and Human Services recommended that the optimal fluoride level in US CWF be uniformly decreased to 0.7 ppm. (57) This recommendation was made in light of widening exposure to fluoride sources other than CWF and an increasing prevalence of dental fluorosis. Previously, the fluoride concentration in CWF ranged from 0.7 to 1.2 ppm based

on the precept that water intake varied depending on the ambient air temperature (ie, CWF was 0.7 ppm in hotter areas and 1.2 ppm in colder areas). However, water intake no longer varies with ambient temperature as much as in the past, (58) and as such, there is now a consistent US recommendation of 0.7 ppm of fluoride in CWF.

A number of countries supply CWF to at least 40% of their population, including Australia, Brazil, Canada, Chile, Hong Kong, the Irish Republic, Israel, Malaysia, New Zealand, and Singapore, among others. (59) Water fluoridation is not technically or financially feasible in many parts of the world, including most of Central and South America and Europe, in large part because there are not modern, central

ized water systems. (60) Instead, salt fluoridation (250 ppm), advocated by the World Health Organization, is commercially available (eg, in grocery stores) in more than 30 countries as a source of fluoride for population-based caries prevention. (61)

Because bottled beverages, such as juices, are often produced with fluoridated community water, these liquids contain fluoride. (41) In a study of more than 500 juices and juice-flavored drinks, 43% had a fluoride concentration above 0.6 ppm; grape juice, in particular, often exceeded 1.0 ppm. (62) As Americans consume more soda and juice in place of water and milk, these beverages “diffuse” from fluoridated into nonfluoridated areas and have become increasingly important sources of dietary fluoride. (41) This phenomenon has various implications. First, consumption in nonfluoridated areas of beverages manufactured with fluoridated water, (63) as well as widespread FTP use, mean that notable differences in caries rates between cities with and without CWF, observed in original studies in the 1950s, are no longer as pronounced. Relatively recent CWF effectiveness studies in the United States estimate 25% fewer caries in children who drink optimally fluoridated water compared with those who do not. (64) Second, this makes it more difficult to estimate an individual’s fluoride intake for determining caries or fluorosis risk.

Decisions to fluoridate US community water supplies are usually made by state or local authorities, although there have been ballot initiatives for and against CWF.

Despite overwhelming evidence of CWF's cost-effectiveness and benefit in preventing caries, fluoride still evokes controversy, as evidenced by numerous websites and Internet entries that assert fluoride's toxic effects and advancing conspiracy theories about fluoride. There are 4 common categories of concern about fluoride: (1) fluoride is a toxin, (2) CWF represents mass medication, (3) CWF eliminates individual choice, and (4) CWF results in adverse health effects. Because pediatricians and other health professionals are called on to promote and defend fluoride, it is worthwhile to understand these claims and evidence against them (Table 1).

Fluoride-Containing Dental Products

FLUORIDE SUPPLEMENTS. With recognition of CWF's capacity to prevent caries, other fluoride sources were introduced. The first was fluoride supplements (FSs), as drops or tablets, which became available in the late 1940s as a means to deliver fluoride to children living in communities without CWF. The American Dental Association first published FS recommendations in 1958. (73) FSs are still recommended by the American Dental Association for children older than 6 months who are at high risk for caries and who reside in fluoride-deficient communities. (74) The American Academy of Pediatrics policy about FS dosing and prescribing by pediatricians expired in 2000.

There remains some mixed evidence of the effectiveness of FSs in preventing caries in young children, (75) yet the disadvantages are substantial, including need for prescription, the fact that liquid formulations are ingested so that the fluoride is delivered systemically rather than topically, and higher fluorosis risk in young children using FSs. (76)(77)(78)(79) The preponderance of strong research evidence supporting the relative advantages of FTP over FSs led Canada, (79) England, (80) Australia, (81) New Zealand, (82) and the European Union (83) to recommend against regular use of FSs in favor of promoting FTP use in young children instead.

FLUORIDE TOOTHPASTE. The 1960s brought direct consumer marketing of FTP. Toothbrushing with FTP is a valuable delivery system for topical fluoride. After brushing with FTP, fluoride levels peak in saliva and then remain at low concentrations for 2 to 6 hours, providing fluoride for enamel remineralization. (33) In the United States, over-the-counter FTP, including those marketed for children, are allowed by the Food and Drug Administration (FDA) to contain either 1,000 ppm of fluoride (1.0 mg of fluoride per gram of toothpaste, in the form of 0.76% sodium monofluorophosphate) or 1,100 ppm of

fluoride (1.1 mg of fluoride per gram of toothpaste as 0.24% sodium fluoride or 0.0454% stannous fluoride). Lower-concentration FTP (eg, 250-550 ppm) is available in other countries. However, on systematic review, these toothpastes did not consistently reduce caries. (84) Lower-concentration FTP is not approved by the FDA for sale in the United States.

FTP has many advantages over FSs, including that FTP works topically, is widely available in grocery and drug stores, does not require a prescription, and is much less expensive (<1 cent per day for FTP compared with 52 cents per day for fluoride drops; Colgate 360 Anticavity Fluoride Toothpaste [Dora the Explorer], 4.6 oz (130 g), costs \$2.99 on drugstore.com and would last more than 1 year at 50 mg per brushing or 100 mg of paste per day, and a 1-month supply of FSs [FLURA-DROPS], 0.25 mg per drop, at Costco costs \$15.57 for a 30-day supply). Furthermore, FTP is widely used by older children and adults, therefore providing opportunities for modeling and instilling a lifelong habit early in life. There is a large body of strong research evidence about benefits of FTP in preventing caries. On systematic review, daily FTP use resulted in 24% fewer caries in permanent teeth and 13% fewer caries in primary teeth, on average, when compared with nonfluoride toothpaste. (85) Furthermore, strong research evidence indicates that FTP's beneficial effects are increased with (1) higher fluoride concentration toothpaste (trials indicate 6% fewer carious lesions, on average, with every 500-ppm increase in FTP fluoride concentration >1,000 ppm), (86) (2) twice-daily use (with a caries preventive fraction of 14% when brushing twice a day compared with once daily), (87) (88) and (3) parent-supervised brushing. (87)(89) Fewer data assessing the effect of earlier FTP initiation on caries are available. Research evidence from cross-sectional and population-based surveys in Europe found significantly lower prevalence of caries at 5 years and older when children began brushing with FTP before 1 year of age compared with those who started after 2 or 3 years of age. (89)(90) However, earlier FTP use is associated with increased fluorosis risk, (34)(76)(77)(78)(79) presumably because very young children will swallow some FTP until they learn to spit out the residue.

Concern over young children swallowing toothpaste has led to ongoing questions about the right age to start use of FTP. Part of the confusion results from difficult-to-interpret recommendations. For example, the label on the FTP package (as required by the FDA) states that parents should ask their physician or dentist whether a child younger than 2 years should use FTP. In response, the Centers for Disease Control and Prevention advises

Table 1. Antifluoridation Assertions and the Facts

Antifluoridation Assertions	Facts
<p>"Fluoride is 'a toxin' added to the public water system." "Fluoride is more toxic than lead."</p> <p>"Evidence for the toxic effects of FTP is found on the warning label on FTP labels—"Keep out of reach of children under 6 years of age. If more than used for brushing is accidentally swallowed, get medical help or contact Poison Control right away."</p>	<ul style="list-style-type: none"> • Fluoride is naturally present at varying concentrations in all bodies of water; the concentration of fluoride in ocean water is 1.2 ppm. • An estimated 57.4 million people worldwide drink naturally fluoridated water in which fluoride is already present at approximately 1 ppm. (59) • Unlike fluoride and other micronutrients, there is no safe threshold for lead exposure. • There is an optimal range of fluoride intake at which the effects are beneficial (ie, fewer dental caries). (41) At lower than optimal intake, more caries are observed; at higher than optimal intake, fluorosis and other adverse effects occur. (41) • Nothing is unique about fluoride's potential for toxicity at excess levels of intake relative to other micronutrients. Analogously, taking one iron tablet prevents anemia but taking higher amounts exposes a child to excess iron, which is dangerous and should also prompt urgent medical attention.
"CWF represents 'mass medication.'"	<ul style="list-style-type: none"> • Medications are used to treat disease. CWF is not intended to treat disease but to prevent it on a population level. • Prescription FTP or FV dispensed by dentists can be used to treat caries but at 100- to 1,000-fold higher concentrations than what is present in optimally fluoridated water.
<p>"CWF eliminates individual choice about fluoride."</p> <p>"People who want fluoride can take fluoride supplements."</p>	<ul style="list-style-type: none"> • CWF helps to equalize risk of caries across socioeconomic groups in a way that fluoride taken on an individual basis does not. (65) • Unlike supplements, CWF is effective at preventing cavities in individuals of all ages. (35)(56)(64) • Supplements are associated with higher levels of dental fluorosis. (66) • Individual choice is still possible in that one can opt out of drinking tap water.
"Fluoride results in adverse health effects," such as increased risk for diminished IQ, hip fracture, arthritis, Alzheimer's disease, cancer, etc.	<ul style="list-style-type: none"> • There is no established evidence for an association between CWF and any disease or intellectual impairment. (67)(68)(69) Drinking fluoridated water is associated with dental fluorosis, most of which is mild or very mild in the United States. (44) • A particularly persistent claim is that drinking fluoridated water increases risk of osteosarcoma in boys. Initial concerns were based on a rat study in which rats were given extremely high levels of fluoride in their water. Subsequently, male rats experienced "marginally higher" osteosarcoma rates in irradiated limbs. (70) • The balance of evidence from well-designed case-control and population-based studies in humans indicates no credible evidence for a link between osteosarcoma and CWF. (67)(68)(69)(71)(72)
CWF=community water fluoridation; FTP=fluoride toothpaste; FV=fluoride varnish.	

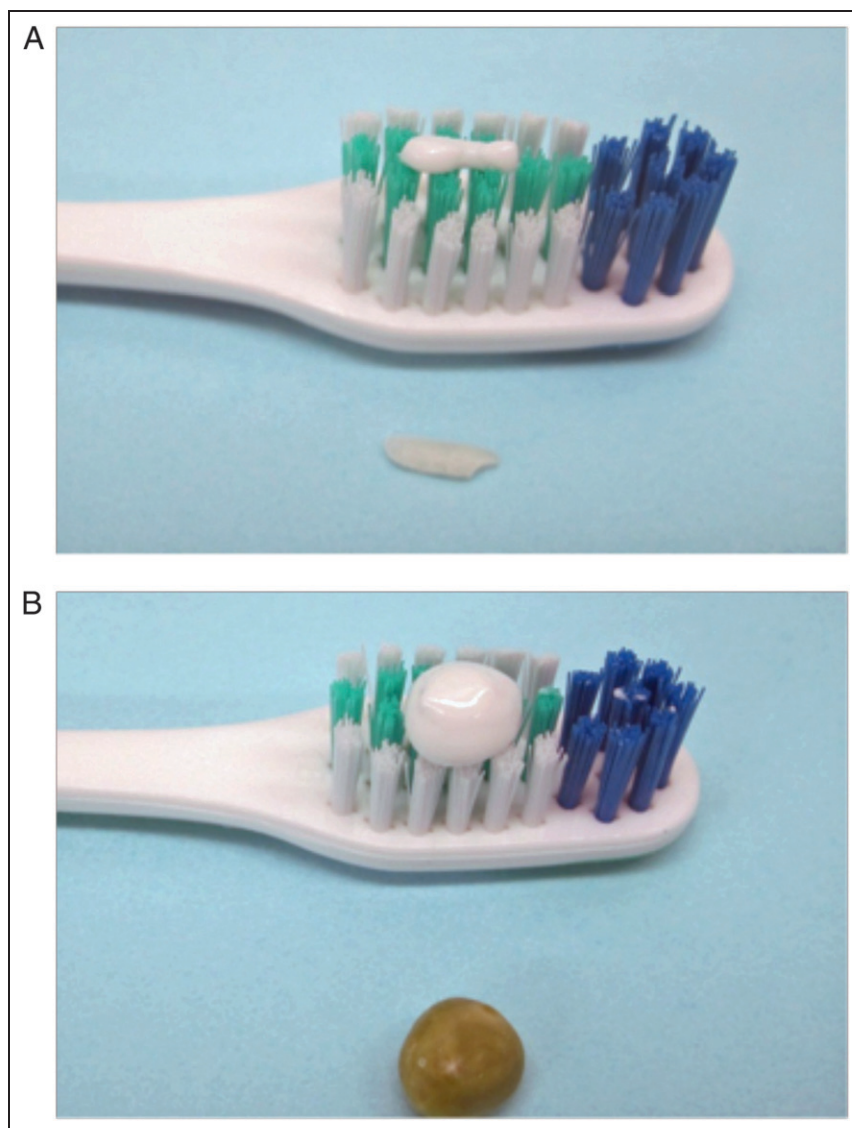


Figure 5. Using an analytic laboratory scale (Mettler Toledo, Columbus, OH), a rice-grain-size and pea-size amount of fluoride toothpaste (FTP) were weighed. A rice-grain-size amount of 1,100-ppm FTP weighed 50 mg and contained 0.055 mg of fluoride. A pea-size amount of 1,100-ppm FTP weighed 250 mg and contained 0.27 mg of fluoride (photographs courtesy of Katherine Lewis, PhD).

health professionals to “consider the fluoride level in the community drinking water, other sources of fluoride, and factors likely to affect susceptibility to dental caries when weighing the risk and benefits of using FTP (before age 2 years).” (34) Given the difficult task of accurately determining how much daily fluoride a child consumes or ascertaining a child’s susceptibility to caries, it is a potentially formidable challenge for pediatricians to advise parents about when a child should begin using FTP. To

make matters more confusing, commercial messaging about the safety of fluoride-free training toothpastes implies that FTP is unsafe for young children. Such messages may lead parents to inaccurately attribute greater hazard to swallowing toothpaste than actually exists (C. Lewis, unpublished data, 2011) and, as a consequence, may potentially limit parents’ use of and the beneficial effects of FTP. The Maternal and Child Health Bureau convened an expert panel in 2007, which recommended, based on some research evidence and consensus, that children younger than 2 years at high risk for caries should use a “smear” of FTP twice daily; however data (90)(91) mentioned in the previous paragraph have also suggested that all children could potentially benefit from starting FTP use before age 1 year.

Empirically, using a small amount of FTP means less is swallowed and thus there is a lower fluorosis risk. Two-year-olds ingest an average of approximately two-thirds of the toothpaste used in brushing. (92) Given this, if a child uses a rice-grain-size amount (approximately 50 mg of paste) of FTP (Figure 5) during twice-daily brushing, he/she gains the beneficial effect of topical fluoride and ingests only approximately 0.08 mg of fluoride, which is much less than is swallowed when taking fluoride drops (0.25-1.0 mg per 1 mL) and is substantially below the threshold for increased fluorosis risk of 0.05 to 0.07 mg/kg daily (in the above scenario a 10-kg child would

consume 0.008 mg/kg of fluoride). Rinsing after brushing is contraindicated based on strong research evidence. For young children who do not know how to spit, rinsing causes more FTP to be swallowed. (92) Among older children, rinsing and spitting out the residue reduce the beneficial effect of the fluoride and result in more caries. (93)(94)

How the balance of risks and benefits of early FTP is perceived has led countries to adopt different recommendations, based on some research evidence and consensus,

about what age to start use of FTP. One approach, currently used in the United States, Australia, and Canada, is based on risk stratification—with children at high risk of caries advised to begin use of FTP at first tooth eruption, (95) whereas children at low risk of caries should wait until 2 years of age (or 18 months in Australia (81) and 3 years in Canada (79)) before using FTP. The other approach, used in England, recommends that *all* children, beginning in infancy, have their teeth brushed twice daily with a “smear” of at least 1,000 ppm of FTP. Furthermore, in England, the recommended amount of FTP per brushing increases to pea-size (approximately 250 mg of paste), and the recommended fluoride concentration in the FTP increases to 1,350 to 1,500 ppm for children 3 years and older. (80)

There is need for high-quality studies focused on relative risks and benefits of early FTP use. In the meanwhile, there are reasons to consider adopting England’s strategy of universal and early FTP initiation in the United States: (1) young children at low risk of caries also experience caries at not inconsequential levels (2); (2) caries prevalence among young children is unacceptably

high and has increased (2); (3) even if a child does not spit after brushing with a rice-grain-size amount of FTP, fluoride intake from FTP use 2 times per day is well below the fluorosis-risk level; (4) it establishes a good habit early; and (5) it places appropriate emphasis on disease prevention.

OTHER FLUORIDE-CONTAINING DENTAL PRODUCTS.

Dental professionals rely on a variety of fluoride-containing products, including foam, gel varnish, prescription-strength toothpaste, and mouthrinse, for caries prevention and treatment. The most thoroughly evaluated for pediatric use are fluoride gels and varnish. Applying these highly concentrated fluoride products to teeth, using a dual arch tray for gel or brush to paint on varnish, leaves a fluoride-calcium compound on tooth enamel that releases fluoride whenever biofilm (ie, plaque) pH decreases. (96) Both fluoride gel (97) and varnish (98) are effective in preventing caries, based on strong research evidence, but FV has a number of advantages over gels, including that FV can be used on infants and toddlers (gel is too easily swallowed), adheres better to the tooth’s enamel surface, and allows for longer sustained levels of fluoride in the

Table 2. Useful Information for Pediatricians About Fluoride in Water and Other Beverages

1. The EPA oversees regulations for drinking water provided by public water systems. Naturally occurring fluoride levels in community water supply are not allowed to exceed 4 ppm, and water suppliers are required to notify consumers if the fluoride concentration of the water exceeds 2 ppm. (106)
2. The FDA has oversight of FTP and bottled water. It does not require the label of bottled water to list the presence of fluoride unless fluoride has been added. (107) Some bottled water companies sell optimally fluoridated water (<http://www.bottledwater.org/fluoride>).
3. Well water contains variable amounts of fluoride, ranging from 0 to 7.22 ppm in one study. (108) The only way to know the fluoride content of well water is to have it tested. Most state health departments have lists of local certified water testing labs. Some state universities will conduct fluoride testing on water samples for about \$15–20. National Testing Labs offers residential water testing for fluoride for about \$50 (www.watercheck.com).
4. Reverse osmosis and distillation remove virtually all fluoride from water. (109) UV light exposure and water softeners do not change the fluoride content of the water. (110)
5. Under-the-sink, faucet-mount, or pitcher-type activated charcoal filtration units do not affect the fluoride concentration of tap water. (30)
6. Minimal fluoride is present in breast milk or cow’s milk. (111)
7. There is negligible fluoride in powdered infant formula. The fluoride content of infant formula made from powder reflects the fluoride in the water used to prepare it. Preparing infant formula with fluoridated water has been associated with higher risk of fluorosis. (112) The ADA states that formula can be prepared with optimally fluoridated water and that providers need to be “cognizant of the potential risks of enamel fluorosis development,” (113) which is advice that may be difficult to implement on a practical level. There is a lower fluoride intake and theoretically less risk of fluorosis with CWF at 0.7 ppm. (114)
 - For example, a 10-kg infant who drank 28 oz of formula prepared with 0.7 ppm of fluoridated water would consume 0.54 mg of fluoride or 0.054 mg/kg of fluoride, which is approximately the recommended intake.
 - If the water contained 1 ppm, then the infant would consume 0.078 mg/kg of fluoride, in excess of the recommended intake.

ADA=American Dental Association; CWF=community water fluoridation; EPA=Environmental Protection Agency; FDA=Food and Drug Administration; FTP=fluoride toothpaste.

Table 3. Recommendations and Evidence Type for Fluoride-Based Caries Prevention^a

FTP Use

On the basis of strong research evidence, it is recommended that children brush with at least 1,000 ppm of FTP (A) (76)(77) and do not rinse after brushing (A). (84) Other recommendations, based on some research evidence and consensus, include the following:

- Initiate twice daily brushing with a smear of FTP at first tooth eruption in all low-income children (<200% FPL) (B). (95)
- Consider initiation of FTP before age 1 year in all children (C). (78)(79)

Children at High Caries Risk

Low-income families and communities experience more caries. Infants living in low-income households should be considered at high risk for caries (A) (1)

- Low-income children and communities should be prioritized for intensive fluoride-based prevention. It is recommended, based on strong research evidence, that low-income children:
 - On an individual level, receive at least twice-yearly FV application beginning by age 1 year to prevent ECC (A). (92)
 - On a community-level, supervised and classroom-based toothbrushing with FTP (94) should be provided in preschool and elementary school (A) and fluoride mouthrinse programs (93) for older children (>6 years) (A). (92)(116)
- Other recommendations pertaining to low-income children, based on some research evidence and consensus, include the following:
 - Low-income children should receive early and regular professional dental care for caries screening and implementation of primary, secondary, and tertiary prevention (C). (114)
 - Caries risk status should be regularly reevaluated and children reassigned to intensive primary prevention if other caries risk factors are identified (D).

Caries Prevention Anticipatory Guidance

It is recommended that education about caries prevention include the following:

- Frequently consuming sugar-sweetened foods and drinks (including 100% juice) increases caries (A). (117)(118)(119)(120)(121)
 - Taking a bottle/sippy cup with any kind of juice or sugar-sweetened beverage to bed increases caries (C). (122)
- Regularly drinking optimally fluoridated water reduces caries (A). (33)(61)(123)
- Using FTP of at least 1,000 ppm twice daily reduces caries (A). (76)(77)

Research Needs

Longitudinal studies and RCTs are needed to monitor trends and refine fluoride-based preventive recommendations (D).

ECC=early childhood caries; FPL=federal poverty level; FTP=fluoride toothpaste; FV=fluoride varnish; RCT=randomized controlled trial.

^aA: Recommendation based on well-designed RCT, diagnostic studies on relevant population, high-quality meta-analysis, or systematic review.

B: Recommendation based on RCT with minor limitations or overwhelmingly consistent evidence from observational studies. C: Recommendation based on observational studies (case-control and cohort). D: Recommendation based on expert opinion, case reports, reasoning from first principles.

enamel crystal matrix. Furthermore, FV does not require special preparation of teeth, requires only brief training to become adept at its application, is generally acceptable to patients, is portable, and requires little storage space—all of which make it easy to use in nondental settings (eg, in schools, public health clinics, and medical offices). In most states, pediatricians can bill for FV application to low-income children insured by Medicaid.

FV is effective in preventing caries in both primary and permanent teeth. The FDA approves FV as a cavity liner and desensitizing agent. FV is used “off-label” for preventing dental caries. Systematic reviews indicate that FV prevents 46% of permanent tooth caries and 33% of primary tooth caries. (99) (100) FV’s effect differs, depending on a population’s caries prevalence. The number needed to treat to prevent one carious surface in primary dentition ranged from 3.7 children in low-caries communities to 1.6 children in high-caries

communities. Children at high risk of caries should be prioritized for at least twice-yearly FV beginning in infancy to optimize ECC prevention. A well-designed randomized controlled trial in San Francisco, California, demonstrated a preventive fraction of 58% in decayed lesions in children who were enrolled in the study at approximately age 20 months and followed up for 2 years, providing a strong research basis for recommending twice-yearly FV in US children at high risk for caries. (101) In England, guidelines specify that all children receive FV 2 times per year, based on some research evidence and consensus, and children at high risk for caries receive FV 3 to 4 times per year. (80)

Community-Level Fluoride Interventions

Among fluoride-based, community-level strategies, there is strong research evidence of the caries preventive

effectiveness of school fluoride mouthrinse programs, particularly in high-caries populations. (102) However, fluoride mouthrinse should not be used until a child is at least 7 years old because younger children may swallow large amounts. Although supervised toothbrushing with FTP takes place at US Head Start programs, no information could be found about classroom-based toothbrushing programs in US grade schools despite strong research evidence from Europe that such programs are effective. On systematic review, supervised FTP toothbrushing programs in school resulted in a caries preventive fraction of 23%. (103)

Other community-level strategies for caries prevention in young children, also more common in Europe, include free or reduced cost FTP distribution. An English randomized controlled trial that evaluated a free FTP mail distribution program, which was targeted at infants and children living in low-income communities, resulted in significantly fewer carious teeth at ages 5 to 6 years. (105) In the United States, free FTP distribution could be added to the purview of the Supplemental Nutrition Program for Women, Infants, and Children (WIC), which targets low-income families and already provides oral health preventive education at a number of sites. (105)

Conclusions

This article provides an evidence-based overview of fluoride modalities and their preventive properties that will allow pediatricians to effectively promote the appropriate use of fluoride for prevention of dental caries in their patients and communities. Table 2 provides additional information about fluoride in water and other beverages to help answer questions that commonly arise in pediatricians' offices.

Widespread availability of fluoride has decreased the prevalence of caries in the United States. Nevertheless, almost all US adults have caries, and like other chronic diseases, dental decay has its substantive origins in childhood behaviors and environment. Table 3 presents specific recommendations for fluoride-based prevention of caries.

On the basis of strong research evidence, CWF and FTP remain the most effective tools to promote optimal oral health for US children and adults. These 2 modalities should form the cornerstones of caries prevention. Ongoing expansion of CWF will require well-funded media campaigns and other organized efforts to counter misinformation perpetuated by anti-fluoridation groups.

Although additional studies are needed to clarify how to best deliver FTP to very young children, consideration

should be given to initiating FTP use at first tooth eruption as standard caries primary prevention for all US children. On the basis of strong research evidence about the relative advantages of FTP, a number of countries (but not the United States) no longer recommend FSs. Because low-income children experience more caries, they should receive an additional intensive caries primary prevention program composed of, in addition to twice-daily FTP use, at least twice-yearly FV, prioritization for early and regular professional dental care, and targeted community- and school-based caries interventions. A dual-track (standard vs intensive) primary prevention approach emphasizes the importance of caries prevention for all children while also addressing the substantial oral health disparities that adversely affect the health and well-being of millions of US children. (8)

Summary

- On the basis of strong research evidence, fluoride reduces demineralization, enhances remineralization, and strengthens tooth enamel, thus decreasing susceptibility of the tooth to decay from acidic by products of bacterial carbohydrate metabolism.
- On the basis of strong research evidence, community water fluoridation has markedly decreased rates of dental decay in the United States and around the world since it was first implemented in the mid-20th century.
- On the basis of strong research evidence, fluoride's effects on preventing caries are primarily topical. However, drinking fluoridated water exposes the teeth to topical fluoride as does twice daily brushing with fluoride toothpaste and periodic application of fluoride varnish.
- On the basis of strong research evidence, twice daily use of at least 1,000 ppm of fluoride toothpaste reduces dental caries.
- On the basis of strong research evidence, fluoride varnish has important caries prevention properties and should be applied to the teeth of low-income children twice yearly, beginning in the first year of life.
- On the basis of some research evidence, fluoride drops are associated with more dental fluorosis, and because they are swallowed their routine use is inconsistent with the primarily topical mechanism of fluoride's action in preventing caries. A number of countries have reexamined the evidence surrounding fluoride drops and no longer recommend them, in favor of early initiation of fluoride toothpaste instead.
- On the basis of strong evidence, fluoride, like all other micronutrients, has a recommended level of intake at which caries prevention is optimized. At lower levels of intake, more dental caries occur. At high levels of intake, fluorosis and other adverse effects occur.

SELECTED REFERENCES

(NOTE: Selected references appear below. Numbers correspond to the references in the article. The complete list of references is available online at http://pedsinreview.aappublications.org/content/35/1/3/suppl/DCSupplementary_Data.)

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1. As part of your office's orientation process for new patients, you review with a parent the benefits of fluoride varnish application for their 3-year-old. After determining that the child is at high risk for caries, you recommend that fluoride varnish be applied
 - A. At age 6 years.
 - B. Every other year.
 - C. Once a year.
 - D. Twice a year.
 - E. When the first cavity appears.
2. Your community is considering adding fluoride to the community water system. There are very strong opinions both for and against this proposal. You are asked to write an editorial for the local newspaper. On the basis of the available evidence, which of the following statements is true?
 - A. Community fluoridated water (CFW) does not help equalize the risk of dental caries across socioeconomic groups.
 - B. CFW is a secondary prevention method for dental caries.
 - C. Oral fluoride supplementation is more effective than CFW in the prevention of dental caries.
 - D. There has been no change in population exposure to fluoride sources other than CFW since 1950.
 - E. There is an optimal range of fluoride intake at which the effects are beneficial.
3. The most effective tools to promote optimal oral health for US children and adults are community water fluoridation and
 - A. Fluoride mouthrinse use.
 - B. Fluoride toothpaste use.
 - C. Fluoride varnish application.
 - D. Oral fluoride supplements.
 - E. Salt fluoridation intake.

4. Caries disproportionately affects certain individuals and groups. This increased risk is primarily determined by
 - A. Age of the individual.
 - B. Frequency of sugary drink consumption.
 - C. Frequency of tooth brushing.
 - D. Poverty.
 - E. Types of oral bacteria present.
5. Research has clarified the mechanism responsible for the decay inhibitory effects of fluoride. Because of this, fluoride supplementation is beneficial
 - A. Across the lifespan.
 - B. Before the first tooth erupts.
 - C. When permanent dentition is complete.
 - D. When primary dentition is complete.
 - E. When puberty begins.

Parent Resources From the AAP at HealthyChildren.org

- English: <http://www.healthychildren.org/English/healthy-living/oral-health/Pages/FAQ-Fluoride-and-Children.aspx>
- Spanish: <http://www.healthychildren.org/spanish/healthy-living/oral-health/paginas/faq-fluoride-and-children.aspx>
- English: <http://www.healthychildren.org/English/ages-stages/baby/feeding-nutrition/Pages/Fluoride-Supplements.aspx>
- Spanish: <http://www.healthychildren.org/spanish/ages-stages/baby/feeding-nutrition/paginas/fluoride-supplements.aspx>
- English: <http://www.healthychildren.org/English/healthy-living/oral-health/Pages/Water-Fluoridation.aspx>
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